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Experimental investigations of performance and emission characteristics of a compression ignition engine fuelled with diesel pine oil blends and by adding 2-ethoxy ethyl acetate as an additive

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Abstract
Biofuel with fuel additives has been gaining increased attention from engine researches in view of the energy crisis and increasing environmental problem. The present work is aimed at experimental investigation of *2 ethoxy ethyl acetate* as an additive to the diesel biodiesel blends. Experiments were done on a 4 stroke single cylinder diesel engine by varying percentage by volume of *2 ethoxy ethyl acetate* in diesel-biofuel blends. The effects of *2 ethoxy ethyl acetate* on brake thermal efficiency, brake specific fuel consumption and exhaust gas emissions were studied. It was found that brake thermal efficiency increased with increase in blend percentage with 5%, 10% and 15% *2 ethoxy ethyl acetate.* Addition of *2 ethoxy ethyl acetate* shows negative impact on brake specific fuel consumption (BSFC) which decreased with blend percentage while it increases with *2 ethoxy ethyl acetate* percentage. CO emissions decreased significantly while NOx emissions decreased marginally with the increase in 2 ethoxy ethyl acetate percentage.

Keywords: *Biofuel, 2 Ethoxy Ethyl Acetate, 4 stroke single cylinder diesel engine, Engine performance and emissions.*

Introduction
Diesel engines are widely used for transportation and agricultural applications due to their reliability, durability and high thermal efficiency. However, there are two major challenges facing the use of diesel engines. One is related with fossil fuel sustainability and other is related with environmental concern on engine emissions. So far, diesel engines have adopted many technical breakthrough for reducing both fuel consumption and pollutant emissions.
Diesel engines are being used as one of the vital prime movers for generating power and electricity in many industrial and agricultural applications. Reports emanating from research studies on alternate or renewable fuels unanimously predict an unprecedented demand for petroleum fuels by 2030 and the repercussions of this have been already felt by the sudden surge in petroleum prices. In addition to this petroleum fuel demand, its use is also associated with increased environmental problems. Considering the future energy security, sustainability and environmental damage, the study on various alternate, clean and renewable sources of fuel has grabbed the interest and attention of many researchers. Among which, biodiesel is one of the most commonly used alternative fuel for diesel engine.
In this study, we introduce *pine oil* biofuel, which is in contrary to the regular use of trans-esterified biodiesel, for fueling diesel engine. Not much attention has been paid to use *pine oil* in diesel engine and hence significant endeavours have been made to test the characteristics of diesel engine using *pine oil*. *Pine oil,* a renewable source, is synthesized from pine oleoresin which in turn is obtained from pine trees. The thermo physical properties of pure *pine oil* such as density, viscosity, calorific value, flash point, fire point evaluated by instruments. The *pine oil* manifests itself as a light oil liquid biofuel, as its viscosity is too low and the measured properties are found to be suited for its use in diesel engine. For the current study, the *pine oil* being used has been procured form the commercial store and has been utilized as it is.

A number of experimental investigations have been reported with a wide variety of oxygenated additives to improve the fuel properties and engine performance and to reduce emissions. Some of these studies suggested that improvement in particulate emission is directly related to the oxygen content in the blended fuel.

2. Literature Review

R. Vallinayagam [1] A new type of biofuel, pine oil is introduced in this work for the purpose of fueling diesel engine. The viscosity, boiling point and flash point of the reported oil are lower, when compared to that of diesel. Also, the calorific value of pine oil biofuel is comparable to diesel. As a result it can be directly used in diesel engine without trans-esterifying it. pine oil biofuel and their blends of 25%, 50%, 75% with diesel were tested in a single cylinder four stroke, direct injection diesel engine and the combustion, emissions and performance results were compared with diesel. The results show that at full load (hydrocarbons) and smoke emissions by 65%, 30% and 70% respectively, the brake thermal efficiency and maximum heat release rate increases by 5% and 27% respectively. However, the NOx (oxides of Nitrogen) emission is higher than that of diesel fuel at full load condition. The experiment work reveals that 100% pine oil can be directly used in diesel engine and potential benefits of pine oil biofuels have been repead.

R. Senthil [2]. Diesel engine are the major contributors of various types of air polluting gases like carbon monoxide, oxides of nitrogen, smoke, etc. Improvement of fuel properties is essential for suppression of Diesel pollutant emissions along with the optimization of design factors and after treatment equipment. Studies conducted in the past have shown that a significant reduction were obtained in the emissions using oxygenates. This paper investigates the performance and emission characteristics of a direct injection Diesel engine fueled with 2 Ethoxy Ethyl Acetate (2 EEA) blends. Different fuel blends which contains 5%, 10% and 15% of 2EEA were prepared and the effect of these blends on performance and emissions were studied on a single cylinder direct injection Diesel engine. The blends were tested under different load conditions and the result showed that 2EEA blended fuels improves the performance of the engine and reduce the emission level significantly.

M. Logananthan [3]. In this study, Biodiesel-Diemthyl Ether (BDE) was tested in a 4-cylinder direct injection diesel engine to investigate the performance and emission characteristics of the engine under five engine loads at the maximum torque. The engine speed was maintained at 1500 rpm. Here the jatropha oil is used as a non edible oil to produce the biodiesel. The dimethyl ether is used as an additive to enhance the engine combustion. The BDE 5 (biodiesel 95% and dimethyl ether5%), BDE 10 (biodiesel 90% and dimethyl ether 10%) and BDE 15 (biodiesel 85% and dimethyl ether 15%) were tested in the engine. The results indicate that when compared with neat jatropha, the engine performance increased and emission level decreased with adding the diethyl ether with methyl ester of Jatropha, the bde 10 blends have 10% higher brake thermal efficiency (BTE). The experimental results showed that the CO, HC and NOx emission is decreased for all BDE blends. The brakes specific fuel consumption (BSFC) decreased for all BDE blends compared to neat jatropha oil.

3. Fuel

Pine oil: In this study, oil derived from oleoresins of pine tree, widely grown for its bark, wood, tar and essential oil, has been decidedly choosen to be used as fuel for diesel engine. *Pine oil*, stable under all conditions of use and storage, is unique in that the feedstock originates from the forest and can be blended with petro-based diesel fuel readily. For the current study, gum pine oil is being used and extracted from *pine oleoresin,* which is traditionally obtained from pine tree, is pale yellow in color with fresh forest smell and is soluble in alcohols and other mineral oils. The estimated world production of pine was reported to be 30,000 tons per annum and the demand for pine oil by 2022 was predicted to be 853,894 tons.

The constituents of pine oil are *terpineol,* which is a tertiary alcohol, dipentene (an isomer of pinene), unreacted pinene and some minor quantities of other by-product and impurities. The *α-pinene*, collected from pine tree, has been converted into *α-terpineol* ($c_{10}H_{18}o$) by acid-catalyzed hydration process. It could be comprehended from the molecular formula of pine oil that it contains inherent oxygen within the structure, which is obtained as the result of the hydration reaction, catalyzed by an acid. Similar to lower alcohols such as ethanol and methanol, pine oil has C, H and O atoms in its structure, emerging as a renewable feedstock in the realm of other alternate fuels. However, contrary to other alcohol type of fuels, pine oil has higher calorific value, which make it as one of the appropriate biofuel to be used in diesel engine. Moreover, pine oil has lower viscosity and boiling point, which could increase the fuel atomization and its vaporization. All the other properties of pine oil, determined by some standard methods, and it qualifies as a potential candidate for diesel engine

Fig 1: Pine Tree

Fig 2: Pine Oil

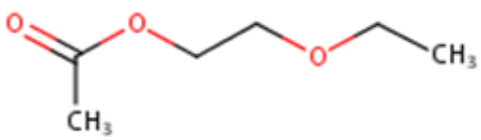

Fig 2: Structure of 2-Ethoxy Ethyl Acetate

2-Ethoxy Ethyl Acetate: 2 EEA is a colourless liquid with a fruity smell at room temperature and normal pressure. 2-Ethoxy Ethyl Acetate (2 EEA) belongs to the group of glycol ethers which are mainly used as solvents, 2 EEA is produced by standard esterification techniques using 2-Ethoxy ethanol, the acid anhydride or chloride and an acid catalyst.

The properties of Diesel, Pine oil and 2-Ethoxy Ethyl Acetate are given below

Properties	Diesel	Pine Oil	2-EEA
Kinematic Viscosity at 40℃ (cSt)	4.2	1.3	2.1
Density at 15℃ kg/m^2	850	875	975
Flash Point (℃)	64	52	51
Fire Point (℃)	70	56	54
Calorific Value (kJ/kg)	43,000	42,800	23,575

4. Experimental Work

The details of the experimental set up are presented. The experimental setup is fabricated to fulfill the objective of the present work. The various components of the experimental set up including modification are presented.

4.1 Experimental Set Up

A Four Stroke Single Cylinder Water Cooled Diesel Engine Test Rig

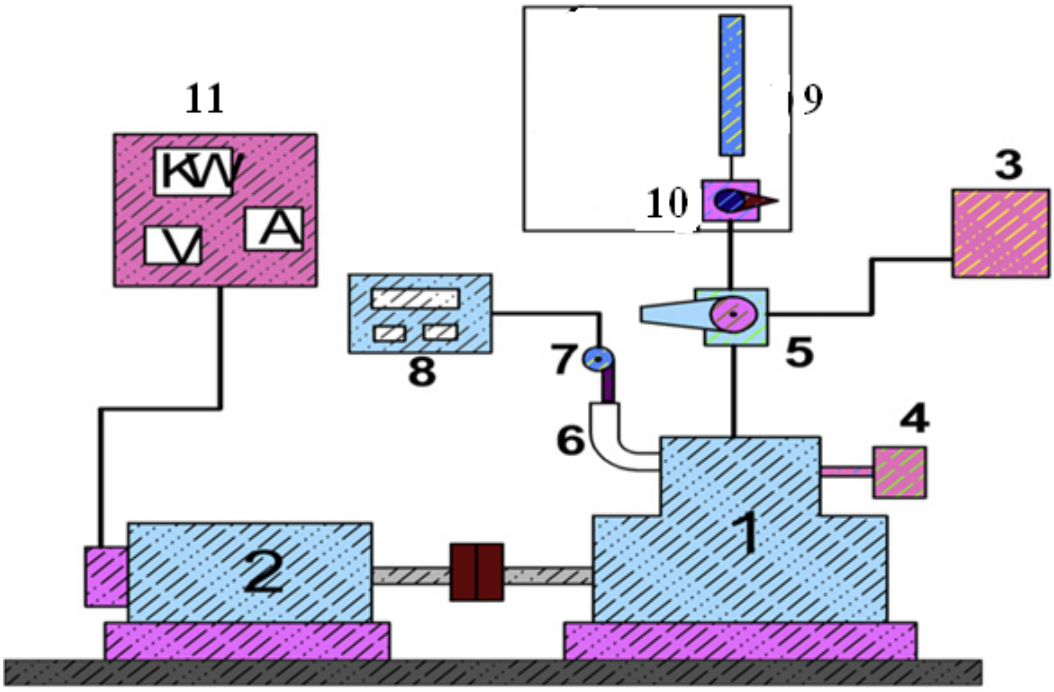

Fig 4: Experimental setup of the 4-Stroke Diesel Engine test rig

The Engine chosen to carry out experimentation is a single cylinder, four stroke, vertical, water cooled, direct injection type CI Engine. This engine can withstand higher pressures encountered and also is used extensively in agriculture and industrial sectors. Therefore this engine is selected for carrying experiments.

Various Parts of Experimental Setup

1. Engine
2. Alternator
3. Diesel tank
4. Air Filter
5. Three way valve
6. Exhaust Pipe
7. Probe
8. Exhaust Gas Analyzer
9. Burette
10. Three way valve
11. Panel Board

In order to analyze the performance and emission characteristics of internal combustion engine, an experimental set-up was developed. In the present work, pine oil biofuel was mixed with diesel in varying proportions 10%, 20%, 30%, 40%, 50% by volume and 2-Ethoxy Ethyl Acetate as an additive was added as 5%, 10%, 15% by volume to the 30% of the biodiesel. The experiment was carried out on a single cylinder water cooled direct injection diesel engine. Eddy current dynamometer is used for loading i.e. electrical loading. The engine specifications are given in Table-1.

Table 1: Test engine specifications

Particulars	Specifications
Model	AVI
Make	Kirloskar Oil Engine Ltd.
Arrangement of cylinders	Vertical
No of cylinders	1
Lubricant	SAE 20/SAE40
Bore	85mm
Stroke length	110mm
Rated speed	1500 rpm
Rated power	5HP
Starting	Hand start with crank handling
Type of cooling	Water cooled

5. Results and Discussions

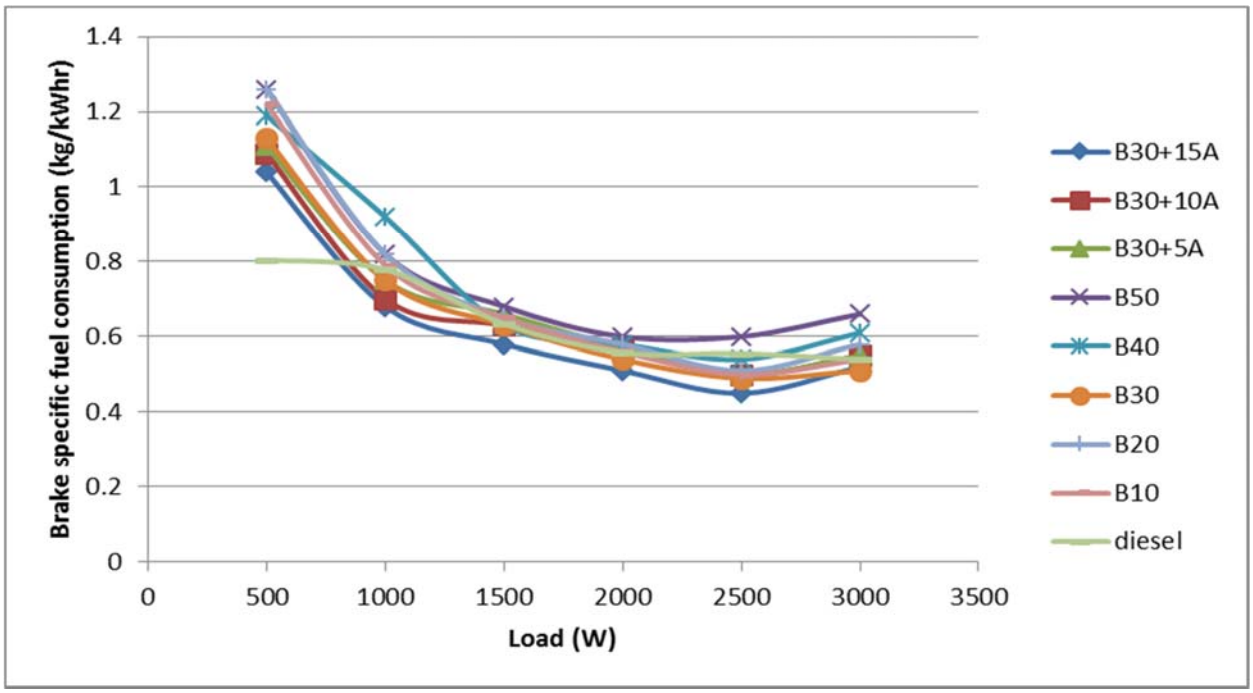

Fig 5: Load vs Brake Specific fuel consumption

Fig 5 shows the brake specific fuel consumption (BSFC) variation with respect to load. It is observed that the readings for the BSFC at different load conditions with different blends, that the BSFC for all the fuel blends tested decreases with increase in load. This is due to higher percentage increase in brake power with load as compared to increase in the fuel consumption. Brake specific fuel consumption is lower for B30+15A at all loads than pure diesel while at 2500W load the decrease is 0.03kg/kWhr.

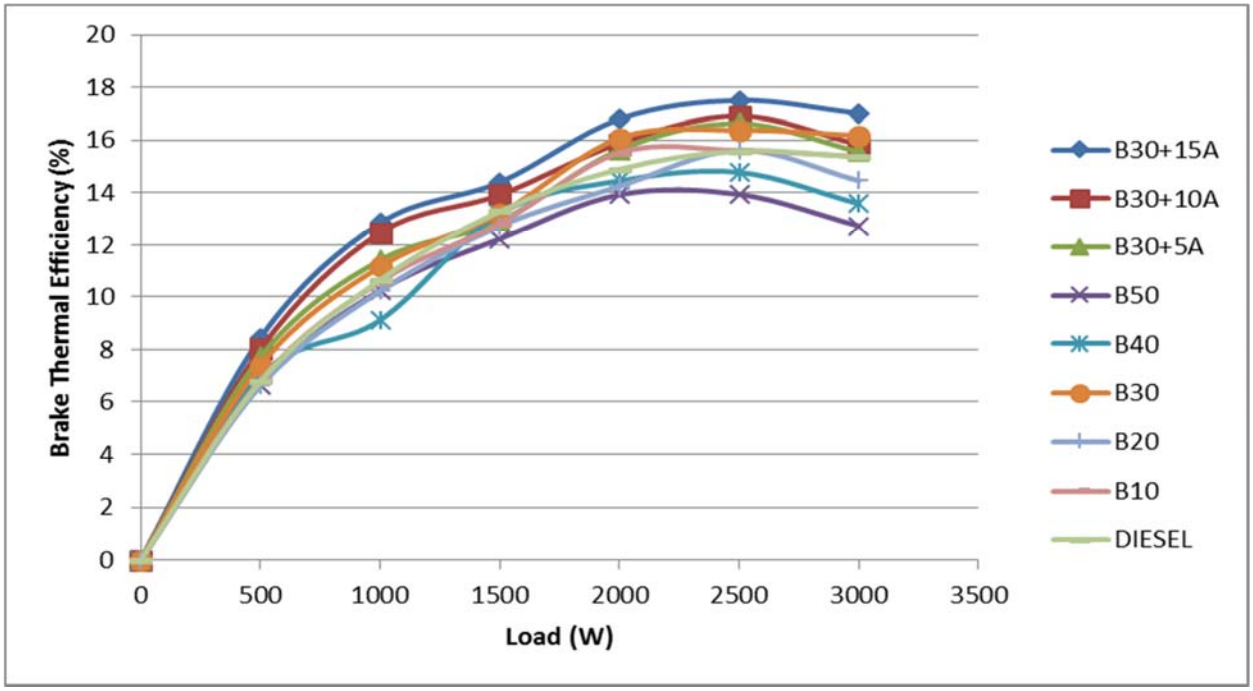

Fig 6: Load vs Brake Thermal Efficiency

Fig 6 shows the brake thermal efficiency (BTE) variation with respect to load. The brake thermal efficiency increases with increase in the percentage of additive. At 2500W (B30+15A) blended fuel produce 1.92% higher brake thermal efficiency than sole diesel. The improvement is due to increase in constant volume combustion and the larger increase of molecules by fuel injection, which leads to better combustion efficiency especially at higher loads.

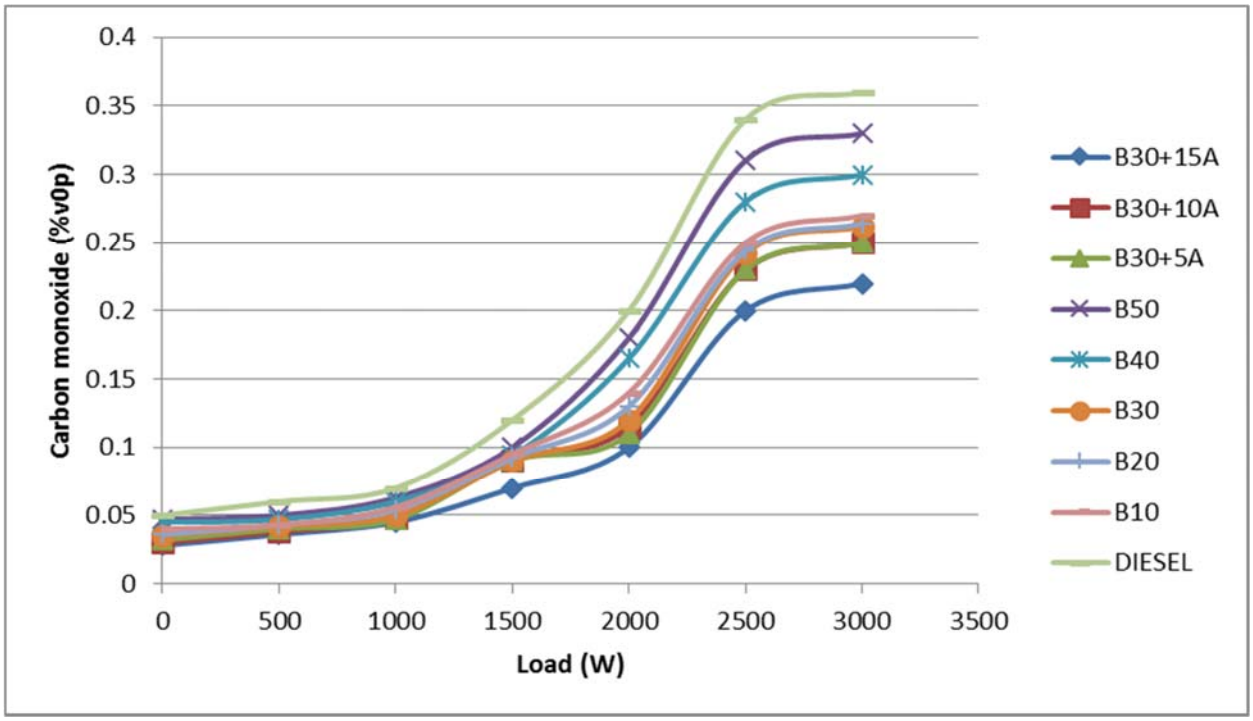

Fig 7: Load vs Carbon monoxide

Fig 7 shows the variation of carbon monoxide (CO) emissions with respect to load. The (B30+15A) blended fuel emits lowest CO emissions than other test fuels. At 3000W (B30+15A) emits 0.14% lower CO emissions than that of diesel. This is due to the presence of more oxygen content in (B30+15A) which makes better combustion resulting reduced CO emissions.

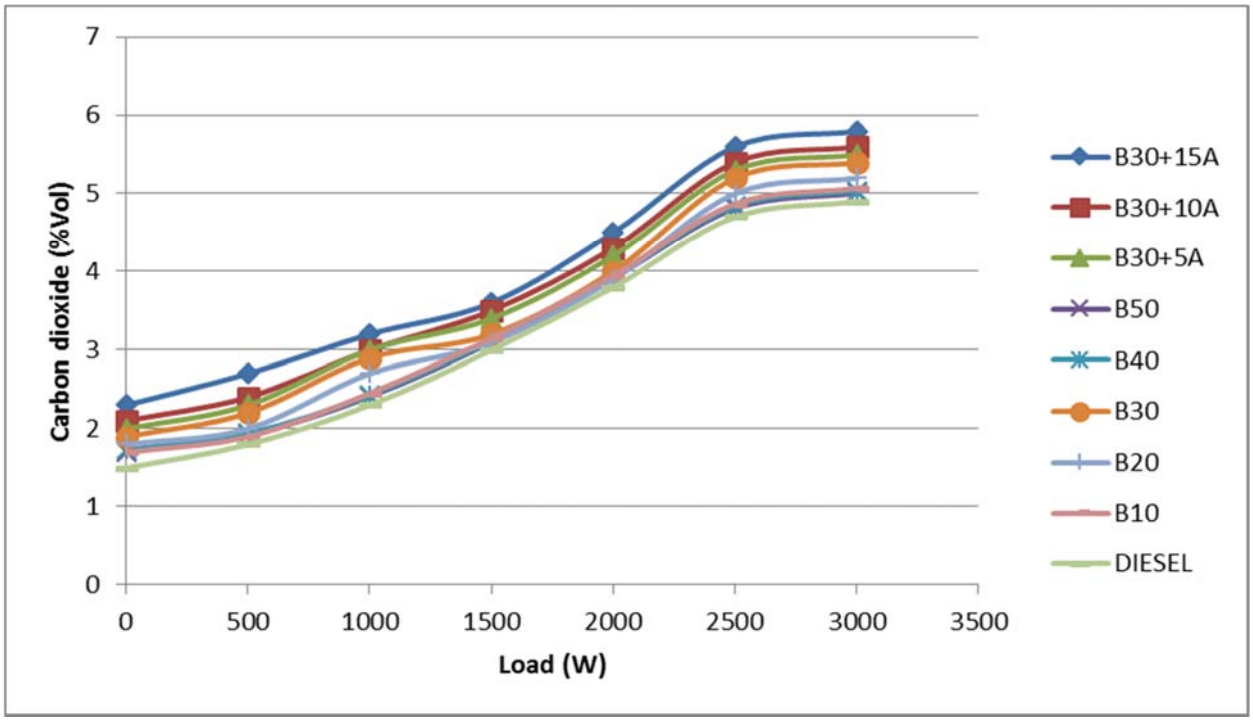

Fig 8: Load vs Carbon dioxide

Fig 8 shows carbon dioxide emissions with respect to load. Carbon dioxide emissions increases with increase in the load for all fuels. It is observed form the figures, the emissions is higher by 0.9% for (B30+15A) blended fuel than diesel. As a general rule, the higher the carbon dioxide reading, the more efficient the engine is operating.

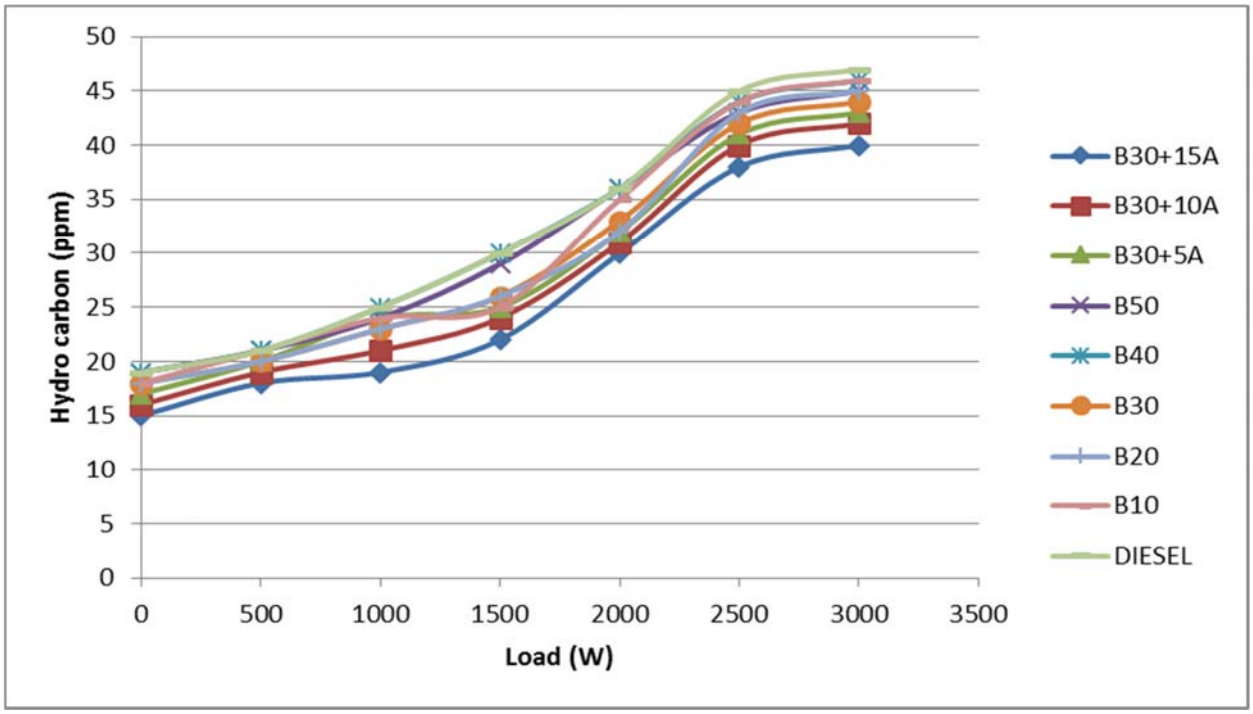

Fig 9: Load vs Hydrocarbons

Fig 9 shows the variation of the HC emission with respect to load. It was observed that, the (B30+15A) blend produce lower HC emission compared to all the test fuels. At 3000W (B30+15A) emits 7ppm lower HC emission than that of diesel. HC emissions tends to reduce as the oxygen content of fuel increases.

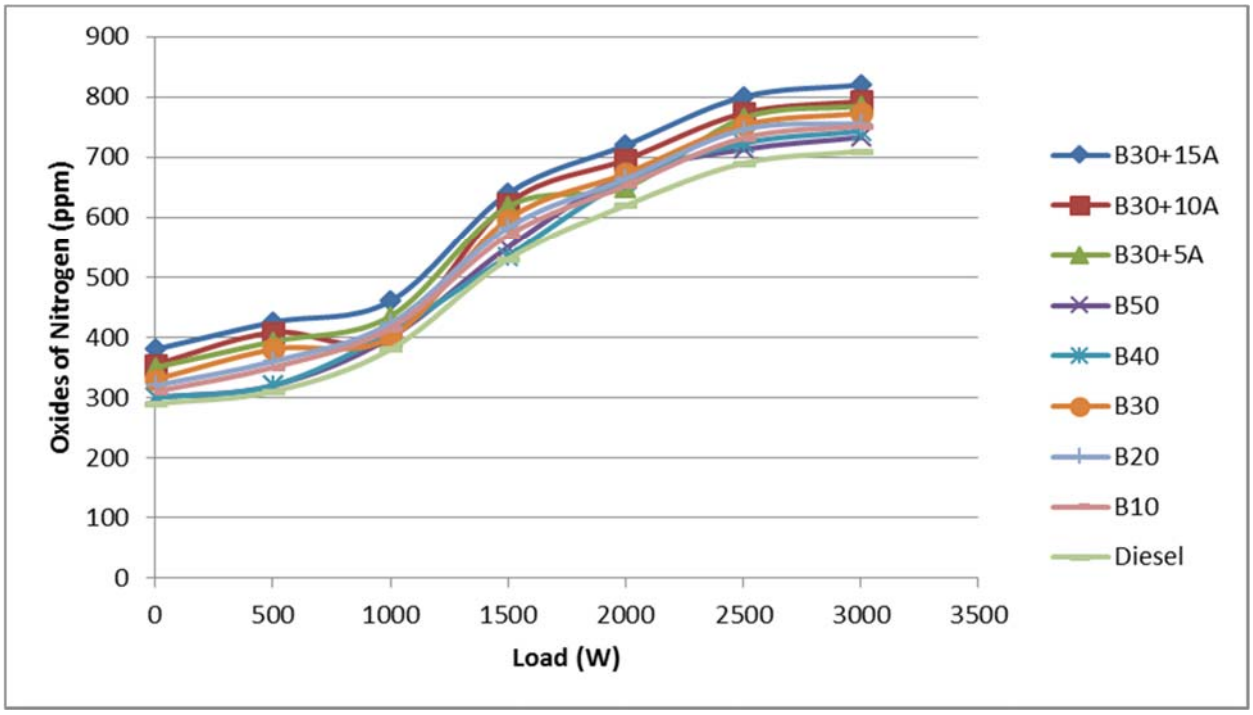

Fig 10: Load vs Oxides of Nitrogen

Fig 10 shows the variation of oxides of nitrogen (NO_X) in the exhaust with respect to load. From the figure it was observed that (B30+15A) blended fuel produce higher NO_X emissions increased by 110ppm at 3000W load compared to sole diesel. The more oxygen content in B30+15A makes combustion better, high peak temperatures which results increased in oxides of nitrogen emissions.

6. Conclusions

The following are the conclusions based on the experimental results obtained while operating single cylinder water cooled diesel engine fuelled with pine oil diesel and 2-Ethoxy Ethyl Acetate additive.

- Brake thermal efficiency is higher for B30+15A at all loads than pure diesel while at 2500W load the increase is 1.92%
- Brake specific fuel consumption is lower for B30+15A at all loads than pure diesel while at 2500W loads the decrease is 0.03%
- The mechanical efficiency is higher for B30+15A at all loads than pure diesel while at 3000W load the increase is 6.22%
- Carbon monoxide emissions at B30+15A are lower by 0.14 %Vol. When compared to pure diesel at 3000W
- Carbon dioxide emissions at B30+15A are higher by 0.9 %Vol. When compared to pure diesel at 3000W.
- Hydro carbon emissions at B30+15A is lower by 7ppm. When compared to pure diesel at 3000W.
- NO_X emissions at B30+15A is higher by 110ppm. When compared to pure diesel at 3000W.

7. Scope of Future Work

The present work can be extended by using EGR setup. The engine can be tested for better performance with various alternative fuels and additives.

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